EXPERIMENTAL STUDY OF HEAT TRANSFER FROM IMPINGING JET WITH UPSTREAM AND DOWNSTREAM CROSSFLOW

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The flow and heat transfer of impingement jets cooling depends on many parameters such as nozzle-to-wall spacing, Reynolds numbers, distance from the stagnation point or design of the injection.The most commonly used geometries in previous studies are axisymetric (circular hole or pipe) and slot (two-dimensional) nozzles [Gardon and Akfirat 1965, Hoogendoorn 1977, Yokobori and al. 1979, Goldstein and al. 1986 and Narayanan and al. 2004]. In internal vane cooling, cool air pass through an impingement channel perforated with multiple holes and then multiple jets impinge on the internal side of the vane (see Fig.1). In the present study, the geometry is a single jet impinging on a flat plate, in order to represent a situation corresponding to the front side and the backside of a vane. In this way, the experimental setup consists of a main crossflow also feeding an injection hole of diameter D_h through a thin plate of thickness t (see Fig.2). A secondary crossflow is fixed between the exit of the nozzle and the impingement wall, to simulate the flow stream evacuation from the leading edge to the trailing edge of the vane. Aerodynamic parameters are the Reynolds numbers Re_{jacket} (characterizing the flow field in the jacket cooling circuit and varying from 20 000 to 60 000), Re_{inj} (in the injection hole and varying from 5 000 to 23 000) and $Re_{air-gap}$ (in the air-gap and varying from 0 to 1000). Geometrical parameters are the nozzle-to-wall distance H with $2 \leq H/D_h \leq 10$ and the thickness of the injection plate t with $0.8 \leq t/D_h \leq 1.2$. The experimental setup is then representative of an internal vane cooling configuration with the assumption of an impingement on a flat plate (typically at the frontside or the backside of the vane) and where the injection plate has a thickness comparable with the injection hole diameter.

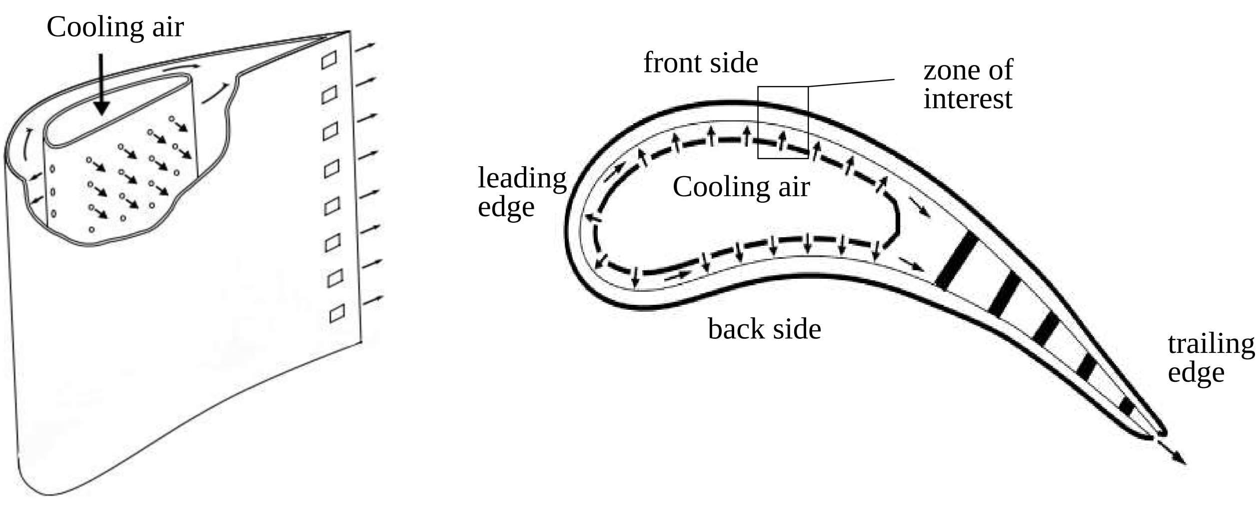

Figure 1: Representation of a vane

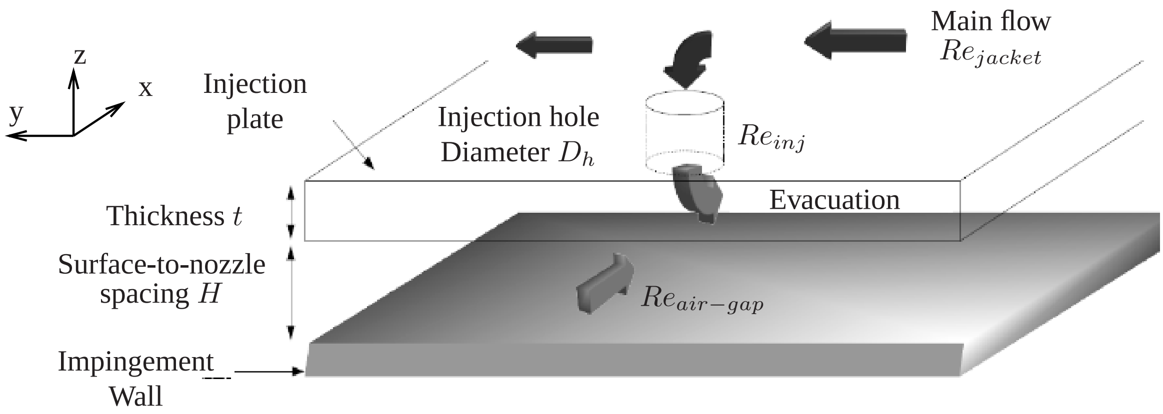

Figure 2: Sketch of the test section

To determine Nusselt number distributions, the impingement wall is heated with an electric circuit and its temperature is measured by InfraRed thermography. The convective heat transfer coefficient is calculated from the balance of different heat fluxes over the impingement plate with the method detailed by Fénot and al.[2005]. It consists of a linear regression of convective heat fluxes $\varphi_{f,conv}$ and wall temperatures T_f on the face exposed to the jet impingement (the front face). An example of Nusselt number Nu distributions on the front face is shown on figure 3.
A non-axisymetric behaviour in the distribution of Nu is observed due to the complexe geometry of the test section. The Nusselt number at the stagnation point Nu_{st} and the averaged Nusselt number $\overline{Nu}$ based on area equivalent to a $10D_h$ diameter disc are also investigated, providing element of comparison of the global efficiency with axisymetric jet. Results show that heat transfers are significantly lower than in previous studies with a jet issuing from a long pipe, and that evolutions of Nu_{st} and $\overline{Nu}$ with respect to the nozzle-to-wall distance is very different compared to cases where a jet issued from a long pipe impinges on a flat plate. Nu_{st} presents two local maxima subsequently lying at

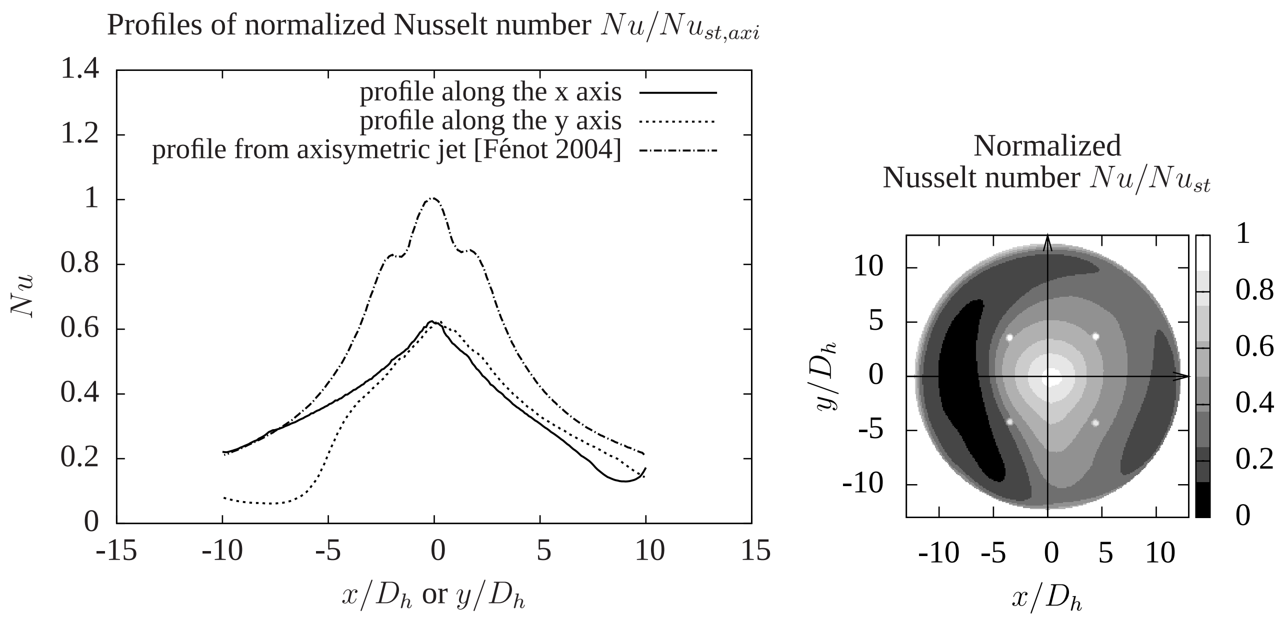

Figure 3: Nusselt number distribution and comparison
with a jet issued from a long pipe [Fénot 2004] at $Re_{inj} = 23000$ and $H/D_h = 2$

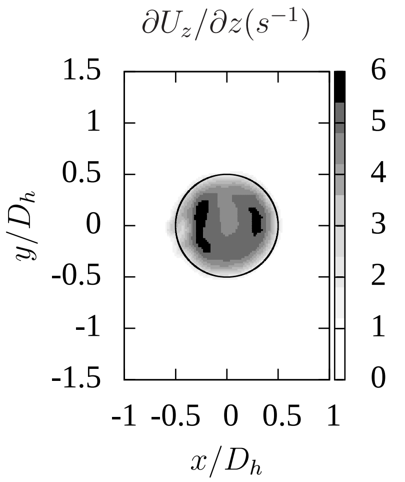

Figure 4: Repartition of $\partial U_z/\partial z$ near the entry of the injection hole

$H/D_h = 4$ and $H/D_h = 6$, and a local minimum at $H/D_h = 5$ while, $\overline{Nu}$ increases until $H/D_h = 6$ and then decreases with the nozzle-to-wall distance. The stagnation point position is not significantly influenced by the geometry.

PIV measurements are undertaken for obtaining a better comprehension of the flow field. In a free jet issuing from a long pipe, the topology of the flow field can be divided into three zones: the potential core, the transition zone and the fully developped zone. In the present study, it appears that the potential core region does not exist and that the flow field is very heterogeneous at the exit of the injection hole. Two main vortices appear at the injection hole. It is shown in figure 4, where the $\partial U_z/\partial z$ component determined from mass conservation equation is drawn at a plane parallel to the injection plate near the entry of the hole. More precisely, these structures are mainly concentrated in lower half portion of the injection hole ($-0.5 \leq y/D_h \leq 0$) (see Fig.5) and a recirculation zone exists in its upper half portion ($0 \leq y/D_h \leq 0.5$). The jet then makes a slight angle but the point of stagnation remains centered which is coherent with Nusselt number distributions. Deeper analysis of the PIV measurements will provide more precise informations on the flow field and on its influence on the heat transfer.

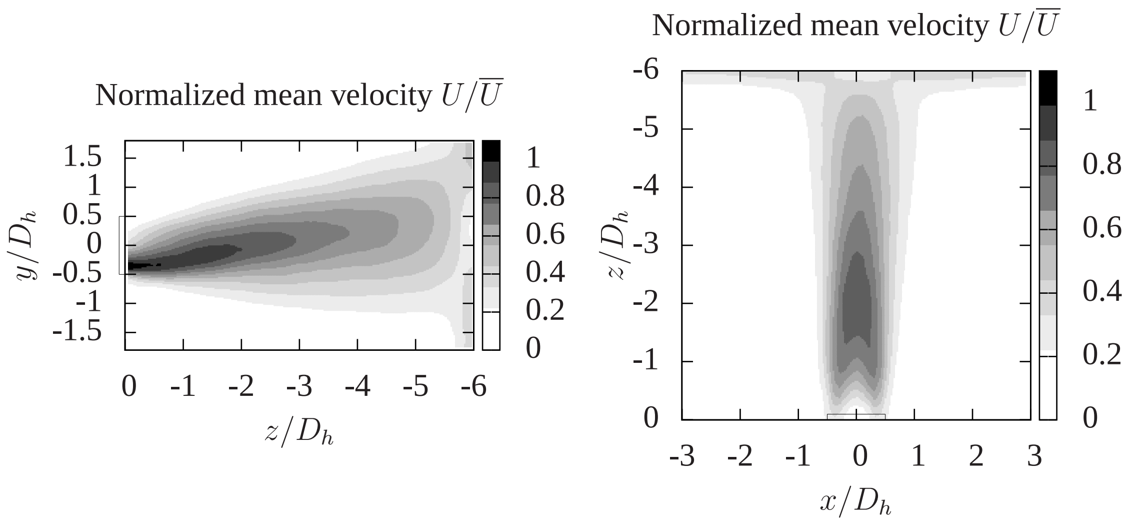

Figure 5: Example of distribution of normalized mean velocity $U/\overline{U}$
in planes containing the center of the hole (with $\overline{U}$ the averaged exit velocity)

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